Applied Soft Computing xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

A hybrid approach based on stochastic competitive Hopfield neural network and efficient genetic algorithm for frequency assignment problem

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ARTICLE INFO

Article history:
Received 24 February 2014
Received in revised form 21 May 2015
Accepted 24 October 2015
Available online xxx

Keywords:
Frequency assignment problem (FAP)
Genetic algorithm (GA)
Hopfield net
Hybrid algorithm

ABSTRACT

This paper presents a hybrid efficient genetic algorithm (EGA) for the stochastic competitive Hopfield (SCH) neural network, which is named SCH–EGA. This approach aims to tackle the frequency assignment problem (FAP). The objective of the FAP in satellite communication system is to minimize the co-channel interference between satellite communication systems by rearranging the frequency assignment so that they can accommodate increasing demands. Our hybrid algorithm involves a stochastic competitive Hopfield neural network (SCHNN) which manages the problem constraints, when a genetic algorithm searches for high quality solutions with the minimum possible cost. Our hybrid algorithm, reflecting a special type of algorithm hybrid thought, owns good adaptability which cannot only deal with the FAP, but also cope with other problems including the clustering, classification, and the maximum clique problem, etc. In this paper, we first propose five optimal strategies to build an efficient genetic algorithm. Then we explore three hybridizations between SCHNN and EGA to discover the best hybrid algorithm. We believe that the comparison can also be helpful for hybridizations between neural networks and other evolutionary algorithms such as the particle swarm optimization algorithm, the artificial bee colony algorithm, etc. In the experiments, our hybrid algorithm obtains better or comparable performance than other algorithms on 5 benchmark problems and 12 large problems randomly generated. Finally, we show that our hybrid algorithm can obtain good results with a small size population.

1. Introduction

The frequency assignment problem (FAP) has received lots of attention these years due to its various applications including satellite communication systems, mobile telephone and TV broadcasting. Frequency assignment problems have arisen in many different situations in the field of wireless communications [1]. In this paper, we focus on the FAP in satellite communication system. In satellite communication system, the reduction of the cochannel interference has become a major factor for determining the system design [2]. Furthermore, due to the necessity of accommodating as many satellites as possible in geostationary orbit, this interference reduction has become an even more important issue with the increase in number of geostationary satellites [3]. To deal with interference reduction in practical situations, the rearrangement of frequency assignments is considered as an effective measure [4].

FAP is a NP-complete combinatorial optimization problem and a lot of approaches have been proposed [5]. The application of neural networks in frequency assignment problems was first proposed by Sengoku et al. [6] and Kunz [7]. Then Kurokawa and Kozuka firstly proposed a Hopfield neural network (HNN) that consist of $M \times M$ neurons for FAP [8–10]. But the neural network of Kurokawa and Kozuka focuses only on minimization of the total interference [11,12]. Funabiki and Nishikawa [32] proposed a gradual neural network(GNN) that consists of $N \times M$ neurons. The disadvantage of GNN is its heavy computation, especially in large problems. Salcedo-Sanz et al. [3] combined a binary Hopfield neural network with simulated annealing (HopSA) for the FAP. The algorithm also cannot deal with large problems because of the excessive computation time. Recently Wang et al. [11] proposed a stochastic competitive Hopfield neural network (SCHNN) [11]. They introduced the stochastic dynamics to help the network escape from local minima. However, avoiding local minima only by the dynamics is not efficient. In these neural networks, the minimizations of the total interference and the largest interference are set in one energy function. In the process of evolution, the energy function will be gradually smaller and stable. Because the two objectives are not fully synchronized, the energy function cannot guarantee that the values of the two objectives decrease at the same time, there may even be a situation that one objective becomes better while another objective becomes worse. So in the process of solving FAP, the better way is to reserve and deal with these two objectives' smallest solutions in each iteration, but it cannot be done in the neural network with only one energy function. There are also many genetic algorithms (GAs) proposed for FAP. Bremermann and Fraser can be considered as the pioneers of GAs [13,14]. Then the algorithm was considerably developed by Holland and Goldberg [15,16]. Cuppini, Kim and Lai were among the first papers found in literature to have applied GA to solve the channel allocation problem [17,18]. Then a lot of new genetic algorithms were proposed for FAP and one of the most recent one is Revueltal [19]. Ngo et al. and Beckmann et al. proposed a new strategy known as the Combined Genetic Algorith (CGA). CGA starts by estimating the lower bound z on bandwidth and its computation time is highly dependent on the z [20,21]. Then Lima et al. introduced two new Dynamic Channel

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http://dx.doi.org/10.1016/j.asoc.2015.10.056
1568-4946/© 2015 Published by Elsevier B.V.

Allocation (DCA) strategies using genetic algorithm. These two strategies are then compared with existing methods [22]. A novel DCA was applied using a Genetic Algorithm for the Wireless Access Network. The authors then categorised the existing channel allocation methods in terms of a Channel Allocation Matrix [23]. Performance of soft computing methods such as genetic programming was improved by embedding it with other potential soft computing methods such as neural network, M5 and statistical methods [24–31]. Furthermore, GA is a search and optimization method and it may get good solutions for FAP. The major differences of the genetic algorithms for FAP lie in the representation of different steps mentioned and the implementation. That is to say, the solutions obtained by GA may be unstable, since the solutions may be influenced by the initialization of the population, the operators of crossover and mutation, the population size and so on. The local restraint is also the weakness of GA. So we cannot get the suitable answer only by GA.

In this paper, we first propose an efficient genetic algorithm (EGA) with five optimal strategies to cope with FAP. Then we try to find a hybrid algorithm which can overcome the shortcomings of the Hopfield-type neural network and the genetic algorithm while keeping their advantages. Three hybridizations between SCHNN and EGA are proposed and compared on five benchmark problems and three large problems in Group 4. The best hybrid algorithm among the three hybridizations is discovered and obtains good performance on all cases. In our research, the hybrid algorithm helps SCHNN to escape from local minima efficiently and increases the ability of EGA to find better solutions by using the neural network as an additional "mutation" operator that injects new good solutions. After that, two strategies for adding the outputs of SCHNN into EGA are discussed. Then SCH–EGA is also compared with other algorithms proposed before. On all cases, SCH–EGA obtains better or comparable performance. At last, in order to show the efficient performance of our hybrid algorithm with a small population, we test the effects of population sizes. In this experiment, our hybrid algorithm can obtain good performance with a small population scale, which reduces computation a lot.

The contributions of this paper are: (1) a novel SCH–EGA algorithm is proposed to cope with the frequency assignment problem and obtains better results than other algorithms. As the good applicability, SCH–EGA can also cope with many other problems including the clustering, classification and the maximum clique problem etc; (2) three hybridizations between the neural network and the genetic algorithm are compared and we believe the comparison can also be helpful for hybrid algorithms between the Hopfield-type neural networks and other evolutionary algorithms, such as the ant colony optimization algorithm, the particle swarm optimization algorithm, the artificial bee colony algorithm, etc.; (3) five optimal strategies are proposed to built an efficient genetic algorithm which can also deal with the FAP very well.

In previous methods for frequency assignment problems, researchers always focused on optimizing the powerful searching ability separately on the aspect of groups or individuals. The algorithms originated from GA almost realized their searching based on the characteristic of population evolution. As an independent algorithm, Hopfield-type neural networks were improved generally on the basis of their neural properties. Differently with these previous researches, in this study, Hopfield-type neural networks treated as chromosomes of genetic algorithm are embedded into genetic algorithm to generate hybrid searching capability for optimization problems. Several hybrid methods we studied reveal the different properties and capability of SCH–EGA, which could produce inspiration to the research of hybrid algorithm. As our algorithm integrates the searching capability of both GA and SCHNN, it shows superior performance on solving FAP. To our knowledge, there are few algorithms adopting the similar hybrid optimization method to solve FAP.

The rest of the paper is organized as follows: in the next section we define and analyze the FAP. In Section 3, we briefly introduce some methods to solve the problem. Section 4 we propose an efficient genetic algorithm(EGA) to cope with FAP. Then the hybrid approach based on stochastic competitive Hopfield neural network (SCHNN) and Efficient Genetic algorithm (EGA) is described. Section 5 shows the performance of the SCH–EGA algorithm, by solving a set of benchmark problems and comparing the results obtained with previous algorithms for the FAP. Finally, Section 6 ends the paper with concluding remarks.

2. Problem definition

In this section, FAP follows the problem formulation by Mizuike [4]. First, we describe the FAP in satellite communications systems as a combinatorial optimization problem with three constraints and two objectives.

Given two adjacent satellite systems (Fig. 1), FAP consists of reducing the inter-system cochannel interference by rearranging the frequency assignment on carriers in system #2(M segments, N carriers), while the assignment in system #1(M segments) remains fixed. Because each carrier usually occupies a different length in a frequency band, Mizuike et al. introduced the segmentation of carriers so that each carrier can be described by a collection of consecutive unit segments. The interference between two M-segment systems is described by a $M \times M$ interference matrix IM (Fig. 3), in which the ijth element e_{ij} stands for the cochannel interference when segment i in system #2 uses a common frequency with segment j in system #1.

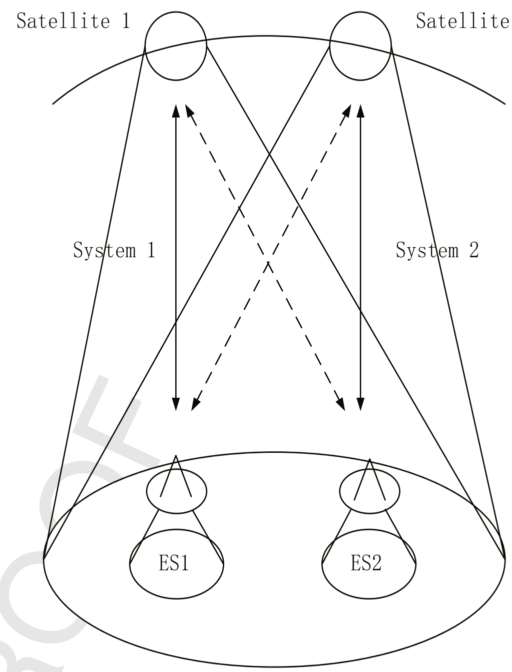

Fig. 1. Intersystem cochannel interference. There are two satellite systems. ES1 and ES2 are two mobile base stations which receive the information from the corresponding satellites.

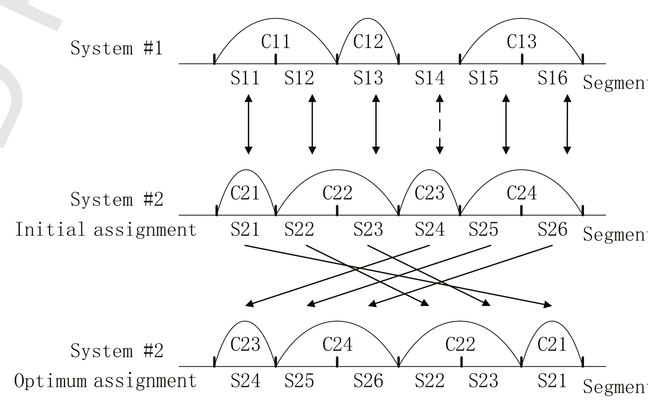

Fig. 2. Cochannel interference model.

The three constraints of FAP are Funabiki and Nishikawa [32]:

(1) Every segment in system #2 must be assigned to a segment in system #1.
(2) Each segment in system #1 can be assigned by at most one segment in system #2.
(3) All segments of each carrier in system #2 must be assigned to consecutive segments in system #1 in the same order.

The two objectives of FAP are shown as follows. Note that the first objective has a higher priority over the second one.

(1) Minimize the largest element of the interference matrix selected in the assignment. (2) Minimize the total interference of all the selected elements.

Fig. 2 shows the characteristics of the combinatorial optimization for FAP. Three and four carriers are utilized there in each satellite system, respectively. The assignment in system #1 remains